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ScienceDirect
Procedia Computer Science 35 (2014) 1165 – 1174
Procedia Computer Science

18th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems - KES2014

A semantic layered architecture for analysis and diagnosis of SME

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Abstract

This article describes the research project MAEOS, whose purpose is to model the organizational and strategic development of SMEs. The main objective of this project is to improve the efficiency and performance of business advice given to this kind of companies by establishing a set of methods and software tools for analysis and diagnosis. In order to achieve this, a multi-disciplinary team was created in which two main research areas are represented: artificial intelligence and management science. In this work several key questions of the knowledge engineering field are addressed by the team: how to extract theoretical knowledge (e.g. from scientific works in management science) and practical one (e.g. from consultants); how to formalize it and use it to assist consultants in their daily work.

Peer-review under responsibility of KES International.
Keywords: ontologies, rules-based systems, set of experience knowledge structure, decisional DNA.

1. Introduction

One of the major difficulties encountered by the Small and Medium Enterprises (SMEs) facing strong competition is the management of their evolution. Thus mastery of change becomes decisive to success. Dealing with the aforementioned changes requires the capacity to perform a global analysis of the whole aspects of the company (e.g. economical, production, organization, human resources, sales, etc.) in conjunction with the ability to interpret this analysis in the perspective of its evolution.

The SMEs involved in this situation often look for the help of consultancy services when they do not have internal resources to do this.

In order to promote the competitiveness of the enterprises, the project MAEOS intends to facilitate their access to affordable and efficient consultancy services so that they are able to manage their own evolution.

The general approach of the consultant is to diagnose the company situation according to his own resources, knowledge and methods. However, these practices should have the following characteristics:

1. advice should be based on a thorough analysis and diagnosis of the current situation of the company with the goal of identifying the dysfunctions in the organization.

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Peer-review under responsibility of KES International.
doi:10.1016/j.procs.2014.08.212

2. recommendations should be based on theoretical dimensions and on selected recommendations already proposed by the consultant in the past.

Therefore, it is essential to combine a big amount of theoretical knowledge about management science (organizational change, strategic change, etc.) and past practical experience of the consultant accumulated during his practice. To cope with this volume of information, various software tools to handle the formalization of theoretical and experience knowledge using semantic technologies were developed during the project.

With the use of these technologies, MAEOS not only integrates itself in the decision making process of consultants during their work, but they will also be able to learn from everyday experiences.

Other technologies from the knowledge engineering field have been proposed to cope with this problem. Case-based reasoning has been use in the clinical diagnosis area [8, 1] , but they do not consider the possible evolution of the underlying knowledge model. Machine learning approaches are also present in the literature, although they arguably require a high cost during system training [6].

In this article, we propose a layered architecture for managing the necessary knowledge. We introduce the capitalization of the cases previously studied by the consultant (the analysis, diagnosis, recommendations and the results of these recommendations) to improve the quality of the business advice delivered to SMEs.

This paper is structured as follows. After presenting the overall architecture of our system, we will come back to some implementation choices before describing the whole prototype developed.

2. Methodology

In the framework of MAEOS project, two software modules have been developed for the moment: a module for diagnosis of the situation of SMEs based on diverse theoretical knowledge and a recommendation module that provides models of recommendations for improving this situation according to a goal, which could be analyzed and supplemented by recommendations provided by the consultant from his previous experience. If these recommendations are followed, an ”ideal” situation of the company should be reached.

The consultant visits an SME and based on his observations, he draws a map of the current situation of the company using the diagnosis module. With the recommendation module, he is able to suggest different courses of action to improve the current identified status of the company.

A few months later (generally 6 monts later), the consultant visits again the same SMEs. The new status is calculated by the diagnosis module of the software, and the ideal situation (induced from the previous visit) and the current situation of SMEs are compared. It can be observed a concordance (the recommendations produced the expected result) or a gap (the recommendations have not been implemented or have not produced the desired result) between these two situations. In any case, the consultant may choose to change the rule-based recommendation based on the outcome of this comparison.

The principle of operation is described in figure 1.

3. The proposed architecture

A layered architecture is the main architectural pattern for large and complex systems. In this pattern, layers are stacked vertically on top of each other. Each layer has a specific functionality providing separation of concerns that, in turn, support to reuse or replace (i.e. changes in a single layer would not affect the others, permitting the continuous operation of the system). Moreover the communication between layers is based on well defined interfaces to provide low coupling.

In particular, in knowledge-based systems, this architecture allows to decouple domain objects and rules from the reasoning mechanisms. For example, new rules can be added without modifying the representation of the concepts of the domain.

Several layered models to manage knowledge intensive tasks are presented in the literature. The one we are interested in, is the KREG Model [16], developed for clinical decision support systems. In general, this kind of architecture consists of four layers:

1. a Knowledge layer, containing the set of domain ontologies of the system.
2. a Rules layer, composed by a set of rules with the criteria for reasoning.

3. an Experience layer, containing the set of decisional events that model the experience of the system
4. a Meta-knowledge layer containing knowledge about the use of the other layers.

Figure 3 presents the proposed four-layered architecture. Further details of each layer are given in the next sections.

Previous works of the team have already tackled many aspects in the Knowledge and Rules layer [19, 18, 11].

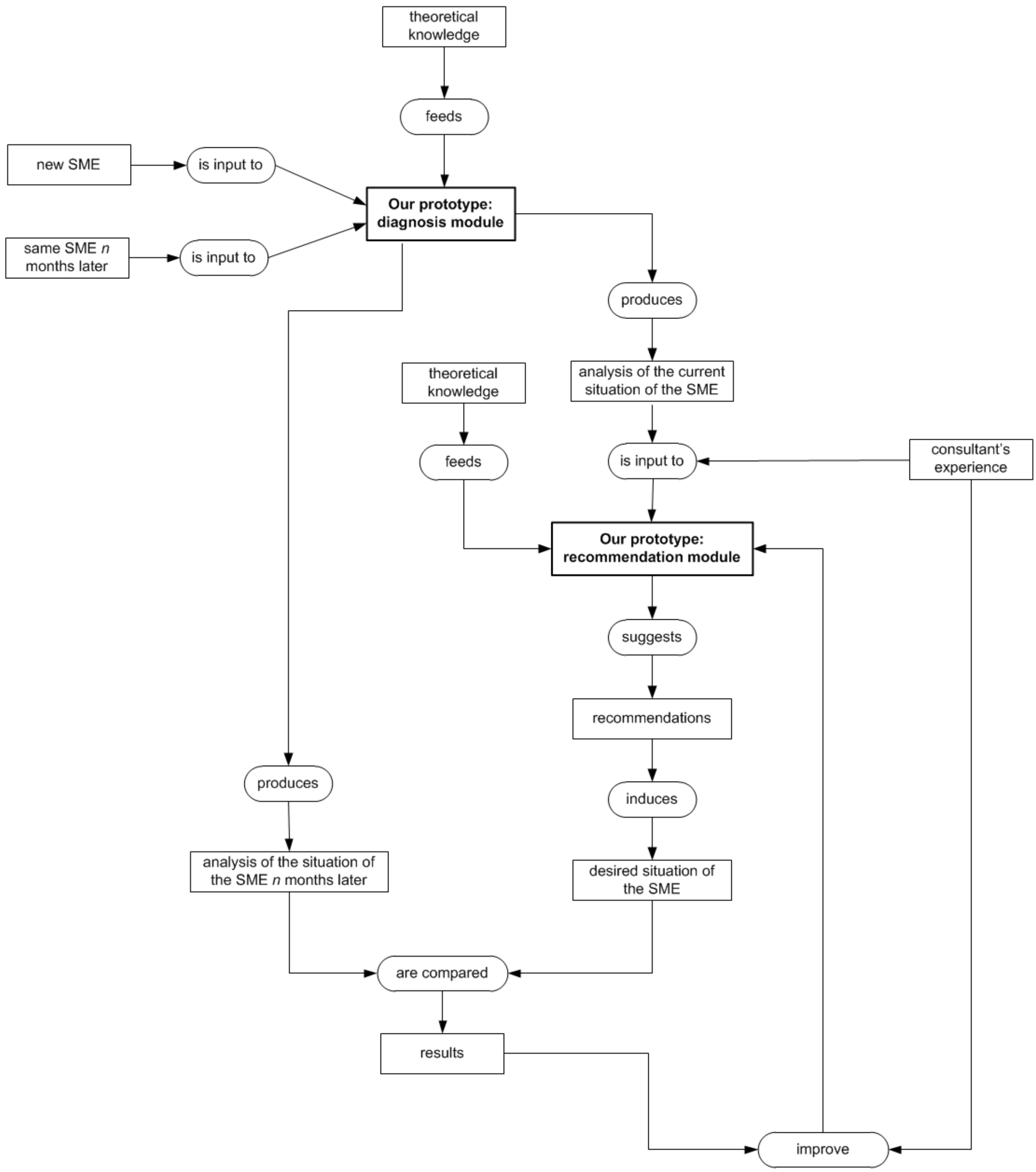

Fig. 1. Operation of the system

The work presented here is concerned, mainly, with the Experience and the Meta-knowledge layer.

3.1. The Knowledge layer

The implementation of MAEOS requires having a computable and structured representation of knowledge. This representation must allow the handling and use of that knowledge in a formal way. To do this, the use of ontologies is the best possible solution.

Several domain ontologies have been developed in this layer and each ontology represents a conceptualization of the knowledge of a specific field in the context of SME (e.g. organization, production, strategy, finance, etc.). Although an ontological study was conducted to provide the necessary theoretical foundations [11], the majority of the existing ontologies provide formal exhaustive models that could be applied to our purposes, but not many among them include reasoning rules to permit analysis or diagnosis. Consequently, our own ontologies and rules bases were developed.

At the moment, four ontologies have been completed and there are others still under development. Concerning the completed ontologies, there is a first one about organization models based on the main works of Mintzberg [9]; a second one about production systems [5] and two specific ones about SME structure and strategy [4, 12]. Figure 3 shows some details of each of them.

For the implementation of these ontologies we have chosen to use the Frames approach, with Protégé[1] and its APIs.

The choice to develop the ontologies according to the Frames approach could seem anachronic, but this is a well-thought choice. Its use is very intuitive and adapted for the managemenent sciences experts who will need, in the end, to develop the ontologies. To facilitate this task, a specific tool for knowledge structuring has been developped, DONNA, that will be presented in section 4.1.

3.2. The Rules layer

This layer manages different types of rules to allow to reason about the instances of the classes in the domain ontologies of the knowledge layer. Since we need to derive new facts from existing instances in the knowledge base, the specification has to be formal.

Three types of rules appear in this layer:

- Rules for diagnosis to obtain the analysis of the current situation of the SME.
- Recommendation rules providing hints to improve the current situation of the company.
- ”Bridge” rules to ensure the semantic equivalence among concepts belonging to different ontologies.

We are using the Jess inference engine [7]. It is capable of storing templates, rules and facts. In our case, the concepts in the ontology are represented by Jess templates, instances of the concepts are represented by Jess facts, and the new knowledge is represented by Jess rules. Another feature of Jess rule engine is that it could define name spaces called ”modules”.

[1] `http://protege.stanford.edu`

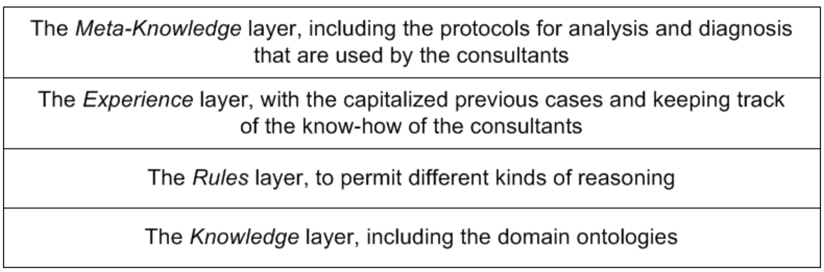

Fig. 2. The proposed four-layered architecture

	Mintzberg	Courtois	Reyes	Boissin
Quantity of concepts	375	379	74	35
Quantity of relationships among concepts	321	346	49	30
Quantity of rules	386	54	72	30

Fig. 3. The ontologies

```
defrule REYE_BOIS::7_semantic_equivalence_7 "ng,_janvier_2011"
  (Reyes_2004::dirigeant {Name != REYE_BOIS_se7} (Ssregle ?x))
  (not (Boissin_2003::chef_d_entreprise (Name REYE_BOIS_se7) (Ssregle ?x)))
  =>
  (assert (Boissin_2003::chef_d_entreprise (Name REYE_BOIS_se7) (Ssregle ?x)
    (ID (getid)))))

(defrule REYE_BOIS_8_semantic_equivalence_7 "ng,_janvier_2011"
  (Boissin_2003::chef_d_entreprise {Name != REYE_BOIS_se7} (Ssregle ?x))
  (not (Reyes_2004::dirigeant (Name REYE_BOIS_se7) (Ssregle ?x)))
  =>
  (assert (Reyes_2004::dirigeant (Name REYE_BOIS_se7) (Ssregle ?x)
    (ID (getid)))))
```

Fig. 4. An example of bridge rules

Modules helps to separate the set of templates, rules and facts of different ontologies. In other words, each module stores the original and new inferred facts for a given ontology. This architecture ensures that the pieces of knowledge are not mixed, but remain in their associated ontology.

Rules are usually expressed as logical implications. A Jess rule is comparable with an `if...then` statement in a procedural language, but it is not used in a procedural way. While `if...then` statements are executed at a specific time and in a specific order, Jess rules are executed whenever their `if` parts (their left-hand-sides or LHSs) are satisfied.

Figure 4 presents two ”bridge” rules indicating that the concept ”dirigeant” in the Reyes [12] ontology is semantically equivalent to the concept ”chef d'entreprise” in the Boissin [4] ontology.

3.3. The Experience layer

This layer intends to capitalize expert knowledge using diverse methods, such as CBR, (Case Based Reasoning) [2] or SOEKS (Set of Experience Knowledge Structure) and DDNA (Decisional DNA) [13, 15].

SOEKS and DDNA have been successfully used in multiple domains, mainly in engineering and medicine; for instance, in diagnosis of Alzheimer and breast cancer [16, 3] or the management of IT projects [10]. However, there are no previous works on the joint use of CBR and DDNA in the field of management science, this is one of the novelties of this project.

Making a diagnosis of the situation of SMEs involves identifying a set of characteristics that are ”present” in this state (current state) and also identifying another set of ”missing” features (the desired state). In this project, we need to effectively assess the current state and decide on actions necessary to achieve the desired state.

Any desired state can, therefore, be obtained by transforming the values of the variables with a transformation function, that is, by performing actions that change the valued of the variables.

By definition, a SOEKS has four components:

- Variables
- Functions
- Restrictions
- Rules

As established before, variables (with their associated value) allow describing the current state of the SME. These variables can also be associated to the values that describe the desired or ideal situation of the SME. Therefore, in a SOEKS, we will choose the variables that need to be transformed from the current state to reach the ideal state, with two values:

- the ”current” value (that is, the value of the variable in the current state)
- the ”desired” value (that is, the value of the variable in the ideal state)

Variables usually involve representing knowledge using an attribute-value language. This is a traditional approach from the origin of knowledge representation. Variables are related among them in the shape of functions. Functions, the second component, describe associations between variables. Therefore, the set of experience uses functions and establishes links among the variables constructing multi objective goals.

Constraints are another form expressing relationships among the variables. A constraint is a restriction of the feasible solutions in a decision problem, and limits the performance of a system with respect to its goals.

Finally, rules are suitable for representing inferences or for associating actions with conditions under which the actions should be performed. They are conditional relationships of the universe of variables.

In conclusion, the four components of the set of experience can be uniquely combined to represent the case of a SME for the consultant.

The reasoning process enables the evolution of the initial set of rules with experience, as it was presented in previous works [16]. More precisely, every time the recommendation module is executed, the system will store both the output of the reasoner and the final recommendation made by the consultant. Recommendations that do not follow the proposition of the reasoner produce an evolution of the set of experience rules.

In the Experience layer, DDNA and SOEKS technologies have been implemented using their ontology form [14], although transformed to be compliant with the Frames formalism that we have retained in this project.

Specific similarity measures to compare the current and ideal situations of the SME during the evaluation phase have been developped.

Let S be the set of all SOEKS. We define IS (the initial state of the SME) as:

$$IS = \{(ontology, concept, attribute, initialCurVal, initialDesVal)\}$$

where every tuple can be seen as a $s \in S$ where the variables are represented by the triples $(ontology, concept, attribute)$ and $initialCurVal$ (initial current value) is the value of a certain $attribute$ in an instance of the considered $ontology$ and $initialDesVal$ (initial desired value) is the desired value for the $attribute$

From this set, we can extract GS (goal state of the SME) with the aspects to be improved ; $GS \subset IS$.

Similarly,we define FS (final state of the SME) S:

$$FS = \{(ontology, concept, attribute, finalCurVal)\}$$

In FD there is no equivalent to $initialDesVal$ because the final state only represents the situation of the company at the second visit of the consultant

Not all the elements in FS are taken into account to calculate the distance amont the initial and final states of the SME. Indeed, only the tuples in FS whose variables $(ontology, concept, attribute)$ appear in the variables of the tuples in GS are considered in the calculation. We will call this set OS (obtained state by the SME); $OS \subset FS$.

It is to be remarked that the cardinality of set OS can be lower than the cardinality of set GS (a certain characteristic of the goal state is no longer present in the obtained state).

Before calculating the distance between GS and OS, three steps are necessary:

1. convert the qualitative attribute values to quantitative values;
2. normalize the obtained quantitative intervals;
3. calculate the distances between every couple of tuples $t_G \in GS$ and $t_O \in OS$, such that t_G and t_O have the same variable $(ontology, concept, attribute)$.

$$dist(t_G, t_O) = \left| initialDesVal_{t_G} - finalCurVal_{t_O} \right|$$

Finally[2],

$$dist(GS, OS) = \begin{cases} \left(\sum dist(t_G, t_O)^2\right)^{\frac{1}{2}} & \text{if } card(GS) = card(OS) \\ \infty & \text{otherwise} \end{cases}$$

These similarity measures will be used later to make evaluated recommendations during the processing of new cases, when the new SME shares the same characteristics with other SMEs already present in the system.

3.4. The Meta-Knowledge layer

This layer (not yet implemented) will include diagnosis models (e.g., about correct or incorrect behavior of companies) and criteria recommendation according to the experience of the consultant. In addition, in their daily tasks, consultants follow certain unwritten protocols (theoretical or not) to diagnose businesses. This layer will also formalize these models and protocols to guide the diagnosis task.

4. The prototype

This section describes the tools developed to implement the layers of the proposed architecture. They are:

- DONNA (Designer for ONtologies with Navigators and Assistant), a Web interface for knowledge structuring, that is for the creation of ontologies and the associated rule bases by the experts in management science.
- DISKO (Development Interface for SME's Knowledge Organization), an user-friendly interface to facilitate the acquisition and visualisation of results, including a multi-agent system [17] for the reasoning associated with diagnosis, called MAMAS (MAEOS Argumentation with a Multi-Agent System)

4.1. DONNA

DONNA is a Web interface for knowledge structuring, that is for the creation of ontologies and the associated rule bases. This tool is designed to be used by the management science experts to formalize the knowledge extracted from scientific articles and books.

DONNA is able to manage ontologies and rules, with conventional features: creation, modification and suppression of ontologies, concepts, relationships among the concepts in an ontology and rules associated with the ontology. Figure 5 depicts the menu of DONNA and part of the form to create a concept.

Another important feature of DONNA is its ability to identify specific types of concepts in the ontology.

On the one hand, there are concrete and abstract concepts in a DONNA ontology[3]. A concrete concept in DONNA is an easily identifiable phenomenon in a real business case. For example, the number of employees, the fact that there is a leader, the number of products (goods or services) offered to the clients, etc.. An abstract concept is more difficult to identify, it generally requires a specific questioning of the consultant at the company. For instance, the identification of the person who is in charge of development strategy or the type of communications that is established among the manager and the employees are abstract concepts.

On the other hand, DONNA is able to identify the concepts that trigger rules. These rules are important because they are the ones that will help the consultant to diagnose the initial situation or to supervise the development of the company. So it is necessary that the concepts that trigger rules be instantiated. By default, these triggering concepts are concrete and concepts that do not trigger rules at all are abstract.

However, a rule with an abstract concept in its premise (or LHS in Jess) may be triggered by a rule that has been previously executed and that has that abstract concept as a conclusion. With these ideas in mind, DONNA

[2]Distances with an infinite value could be obtained. They are evaluated by the consultant to derive a more effective support to the company. These infinite values could arise, for example, when observations during the second visit launch diagnostic rules that are different from those that were launched after the first visit.

[3]The experts in management science use these two terms (concrete/abstract) with a different sense from the one coming from the world of ontologies.

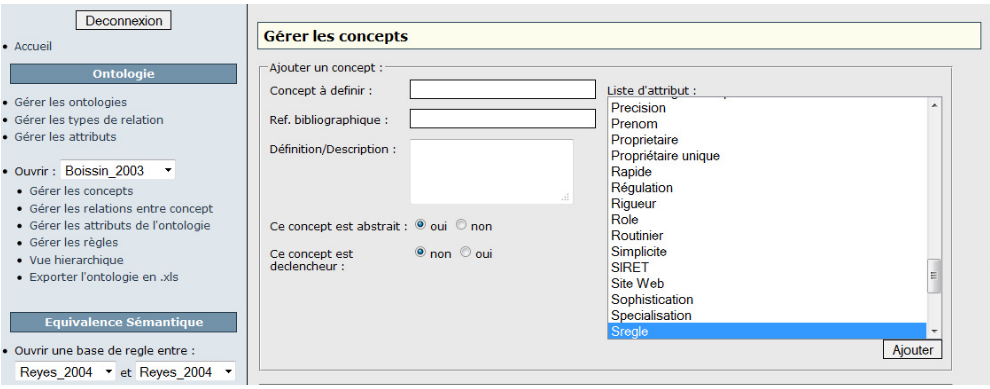

Fig. 5. Concept creation with DONNA

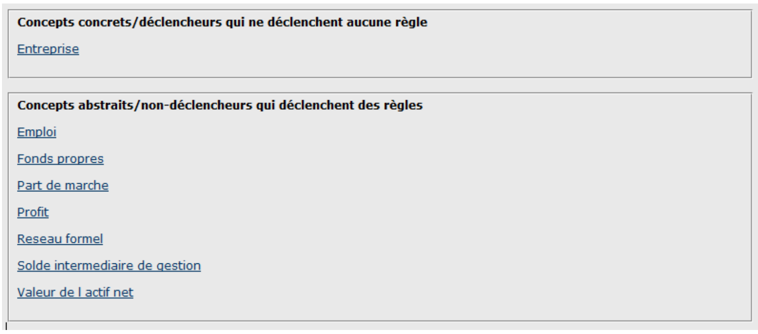

Fig. 6. Analysis of the concepts of the ontologies with DONNA

has mechanisms that permit to identify which is the minimum set of concepts to be instantiated so that all the set of rules may be triggered, directly or indirectly. Figure 6 shows the result of the analysis made by DONNA to identify concepts that trigger rules.

4.2. DISKO

DISKO provides a user-friendly interface to facilitate the acquisition and visualisation of results, with two main goals

- to reason about a real business from the ontologies that have been formalized in DONNA
- to capitalize the past cases in order to assist the reasoning.

It should be noted that the modules for diagnosis and recommendation are already operational and that are currently constrained only by the amount of ontologies formalized in DONNA. The experience capitalization module is under development.

The DISKO interface (figure 7) allows the user to choose the ontology to be instantiated, to visualize the instances in text or graphical mode, to perform the analysis and to launch the diagnosis.

Unlike current trends, which try to represent knowledge in a homogeneous knowledge base that covers the whole domain of a problem, our choice is different. On the contrary we intend to maximize the plurality of each knowledge base with their fields of interest, constraints and richness.

In order to introduce the notion of multiple points of views, the operation process that has been chosen is similar to the one of a panel of experts. Each expert has an area of knowledge and a set of skills. He examines different aspects of the business related to his area of expertise. Once the study is completed, his conclusions are shared with other experts. Finally, a report is created.

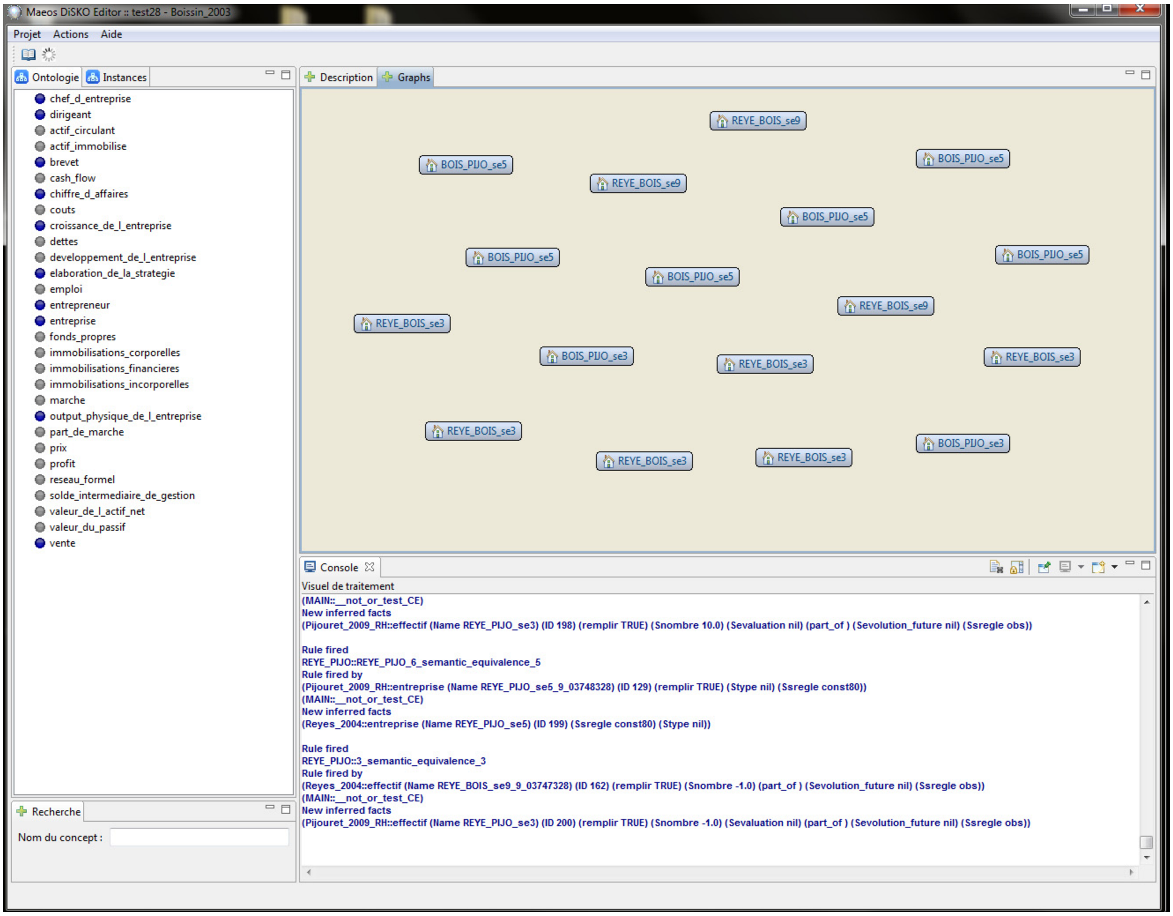

Fig. 7. The DISKO interface

The panel of experts is implemented with a Multi Agent System with a blackboard architecture. This system consists in several knowledge bases on areas relative to business management which are attached to software agents with the ability to exploit their content.

Each agent is associated with a particular knowledge base. Therefore, all agents are characterized by a knowledge domain, a collection of facts and/or rules and a set of meta-data. At the beginning, a set of facts about an organization is entered in the blackboard. Each agent picks up information in it. It accomplishes its deduction or mapping tasks. At the end, it adds the results to the blackboard. The triggering of an agent is made by a set of data corresponding to the characteristics of its knowledge base. The process is considered as finished when the agents have nothing new to add to the blackboard. Communications among the agents in the blackboard is ensured by the ”bridge” rules (section 3.2).

There is also the possibility of examining the logs of the execution of the MAS. The console shows how many agents can infer, the rules that have been launched, and which facts where deduced resulting in instantiation of new concepts.

This prototype has been validated by our industrial partner and used in several precedent test cases.

5. Conclusions

This paper has presented our proposal as well as the first results of the use of a semantic architecture with four layers for the development of a knowledge-based system for assisting consultants in their task of diagnosis and support of SMEs.

The purpose of the developed software is to assist the consultant in the process of thinking and reasoning. This system can help manage a significant amount of knowledge through the proposed formalization.

The main objective of our project is to improve the efficiency and performance of the consulting services proposed to SMEs (and not provide automatic solutions to a problem, as we consider that the expertise of the consultants remains essential).

The results presented here, although preliminary, are encouraging because they show the feasibility of the proposed approach, and open the way to numerous possibilities for the future; in particular, the use of approaches coming from the field of Natural Language Processing (or NLP) for trying to automate the construction of ontologies from texts or the implementation of fuzzy reasoning in the Rules layer.

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